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14 Field and Laboratory Tests of Soil Respiration

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Soil supports a vast amount and diversity of biological activities, therefore, it is generally thought that some measure of soil biological activity would be a valuable indicator of the health or quality of the soil. There have been many techniques used to measure the activity of soil biota. Some of these techniques reflect the activities of specific organisms or groups of organisms whereas other techniques provide an assessment of overall biological activity. Microorganisms play a key role in soil ecology. By decomposing dead plant and animal material, soil microorganisms recycle essential nutrients. Because of these characteristics, an active microbial population is an attribute that is often cited as a key component of good soil quality (Howard, 1947; Waksman, 1927; Turco et al., 1994; Kennedy & Papendick, 1995).

Respiration is a process that reflects biological activity. A distinction must be made between microbial respiration and soil respiration, as often times these two terms are used synonymously. In this chapter, we define soil respiration as the production of CO_2 or consumption of O_2 as a result of the metabolic processes of living organisms in soil. Here microbial respiration is defined as the production of CO_2 or the uptake of O_2 as a result of the metabolism of microorganisms such as bacteria, fungi, algae, and protozoa. Whereas the term microbial respiration refers to the metabolic activity of microorganisms, soil respiration has a more general implication, and indicates the biological activity of the entire soil biota including microorganisms, macroorganisms (such as earthworms, nematodes, and insects), and plant roots. This distinction is important because a vari-

[1]Names of products are included for the benefit of the reader and do not imply endorsement or preferential treatment by USDA.

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ety of different methods for measuring respiration have been developed, and some are more appropriate for determining microbial respiration, while others better represent total soil respiration.

This chapter describes methods for assessment of soil and microbial respiration, and to provide a framework for interpreting these measurements relative to soil quality. It must be pointed out that we will not discuss in detail the limitations and implications of all the available methodology for determining biological and microbial activity in soil. For additional information related to soil respiration measurements, the reader is referred to past review and methods articles (Anderson, 1982; Zibilske, 1994). Rather, we propose two basic methods, both based on quantification of the rate of CO_2 production. The first method, used to assess total biological activity, is based on determination of CO_2 flux rates using chambers placed over the soil surface. The second procedure is used to assess microbial activity, and is based on CO_2 production from sieved, mixed soil in the laboratory under a fixed temperature and moisture regime.

METHODS DESCRIPTION

Soil Respiration: Field Carbon Dioxide Flux Using Soil Covers

Principles of Measurement

Many techniques have been proposed and applied to the quantification of gas flux from soil, but the simplest is the closed chamber method. This technique involves covering the soil with a canister or chamber and measuring gas flux rate by determining changes in concentration of the gas in the headspace of the chamber over time. Typically, soil respiration is determined by monitoring the rate of accumulation of CO_2 in the chamber (as opposed to monitoring decrease in O_2 concentration). The CO_2 accumulating in the chamber is not necessarily only the result of soil microorganisms; CO_2 also is produced by other soil fauna and plant roots.

There are several possible ways to determine CO_2 concentrations. Discrete gas samples can be removed from the chamber using a syringe, and the CO_2 content of the gas samples can be measured using a gas chromatograph or infrared gas analyzer. Carbon dioxide can be trapped during the incubation period in an alkali solution, and the amount of CO_2 determined by titration or by weighing soda lime traps (Anderson & Ingram, 1993). Real-time determinations of CO_2 can be performed by recirculating the chamber headspace gas through a portable infrared gas analyzer. The critical aspect of soil respiration measurements is that the amount of CO_2 emanating from the soil is quantified over a known time period.

There are many tradeoffs that must be considered in deciding upon the appropriate methodology for measuring CO_2. Among the factors that must be considered are cost, ease of application, and biases associated with CO_2 flux determinations. Tradeoffs exist between measurement bias that may exist in the closed chamber technique and the simplicity of this technique. It has often been

observed that CO_2 accumulation in closed chambers is not linear, but rather the rate decreases with time. This effect has been attributed to alteration of the CO_2 gradient within the soil profile, because of CO_2 accumulation within the chamber headspace (Anthony et al., 1995), or CO_2 depletion in the headspace if soda lime is used (Nay et al., 1994). Measurement bias also can result from alterations in temperature and pressure within the chamber, as a result of chamber placement on the soil surface.

Tradeoffs also exist in relation to method of CO_2 measurement. Gas chromatographs and infrared gas analyzers yield accurate, reproducible results; however, the cost of the instrumentation to perform these analyses is high. Alternatively, CO_2 can be determined using Draeger gas detection tubes which cost approximately $3.50 each. We have found the accuracy of these gas detection tubes to be comparable to that obtained with a gas chromatograph (Table 14–1).

Depending upon the CO_2 measurement technology available, a determination must be made regarding number of CO_2 measurements required to quantify the CO_2 flux rate. If instrumentation such as a gas chromatograph or an infrared gas analyzer is available, it is advantageous to make several CO_2 determinations over the course of the incubation. With soda lime trapping or gas analysis tube determinations, usually, only a single time point analysis is performed.

Due to chamber effects, the duration of the period when the soil is covered should be as short as practically possible. Again a tradeoff exists between the length of time required to allow enough accumulation of CO_2 to enable accurate assessment vs. biases that may occur due to prolonged soil coverage. The limitations associated with closed chamber methods do not preclude its use if the method is applied judiciously. It is by far the simplest, and least expensive soil respiration methodology currently available. The following discussion provides a list of materials and procedures required to perform soil respiration measurements using a simple closed chamber coupled with a single time point CO_2 measurement using a Draeger gas analysis tube. This approach is part of the on-farm soil quality methods described in Sarrantonio et al., (1996, this publication).

Table 14–1. Draeger tube vs. gas chromatographic determinations of CO_2 from respiration chambers.

Chamber	Gas chromatograph†	Draeger tube
	% CO_2	
1	0.13	0.15
2	0.17	0.15
3	0.16	0.20
4	0.21	0.25
5	0.18	0.25
6	0.17	0.25
7	0.17	0.25
8	0.14	0.10
Mean‡	0.17	0.20
Std. dev.	0.025	0.06

† Gas chromatograph determinations performed on 8 mL of soil chamber headspace gas collected in evacuated vials using a thermal conductivity detector.

‡ Means are not significantly different ($P > 0.05$) as determined by a Mann Whitney test.

Method 1: Soil Respiration

Materials Required

1. Infiltration ring. Aluminum irrigation pipe, 14.9 cm i.d. (~6 in), cut to 12.7 cm (5 in) length, edge on one end beveled, outside of ring marked at 7.6 cm (3 in) from the bottom of the ring. (See description of soil infiltration measurement).
2. Chamber lid. Can bottom from Number 10 food can (15.3 cm diam.) cut with 2.54 cm (1 in) lip, containing three holes fit with rubber stoppers. Stoppers are red rubber for serum or vaccine bottles and are 1.9 cm long by 0.3 cm thick, tapered from 1.63 cm diam. at the top to 1.43 cm diam. at the bottom.
3. Soil thermometer. Any metal thermometer with a range from 0 to 100°C
4. Draeger gas detection tubes. 0.1% CO_2 sampling tubes.
5. A 140 cc Syringe (plastic).
6. Latex tubing. Two pieces approximately 10 cm (4 in) each, Tubing has inner diameter of 0.64 cm (1/4 in) and a wall thickness of 0.48 cm (3/16 in).
7. Hypodermic needles. 18 to 22 gauge, 2.5 to 3.8 cm (1 in to 1.5 in) long.
8. Watch or timer.

Procedure

1. Install infiltration ring (beveled edge down) to the line marked at 7.6 cm (3 in) into soil using wood block and hand sledge (Fig. 14–1A).
2. Place chamber lid on infiltration ring (Fig. 14–1B) and record time or start timer.
3. After ½ h, attach the latex tubing-Draeger tube-Syringe assembly to the soil chamber by inserting hypodermic needle through one of the chamber lid's rubber stoppers (Fig. 14–1C). As a precaution another syringe needle is placed into one chamber stopper that is at least 4 in away from the rubber stopper used for sampling to prevent formation of a vacuum during the sampling procedure.
4. Slowly draw 100 mL of headspace sample (do this over about a 15 s time period) through an opened 0.1% CO_2 Draeger gas detection tube using the 140 mL syringe for suction (Fig. 14–1D). Note, the Draeger detection tube is a sealed glass tube, and each end must be broken off before gas can be sampled. The Draeger tube is opened by using a 0.16 cm (1/16 in) diameter hole drilled in the syringe plunger handle to break off each end of the tube.
5. After 100 mL of chamber headspace gas has been drawn through the Draeger tube, read CO_2 as percentage by volume on the $N = 1$ scale (100 mL) of the Draeger tube as indicated by the furthest advance of a violet color change down the tube. If the advancing color line is not parallel with the gradation lines, estimate it's average position.

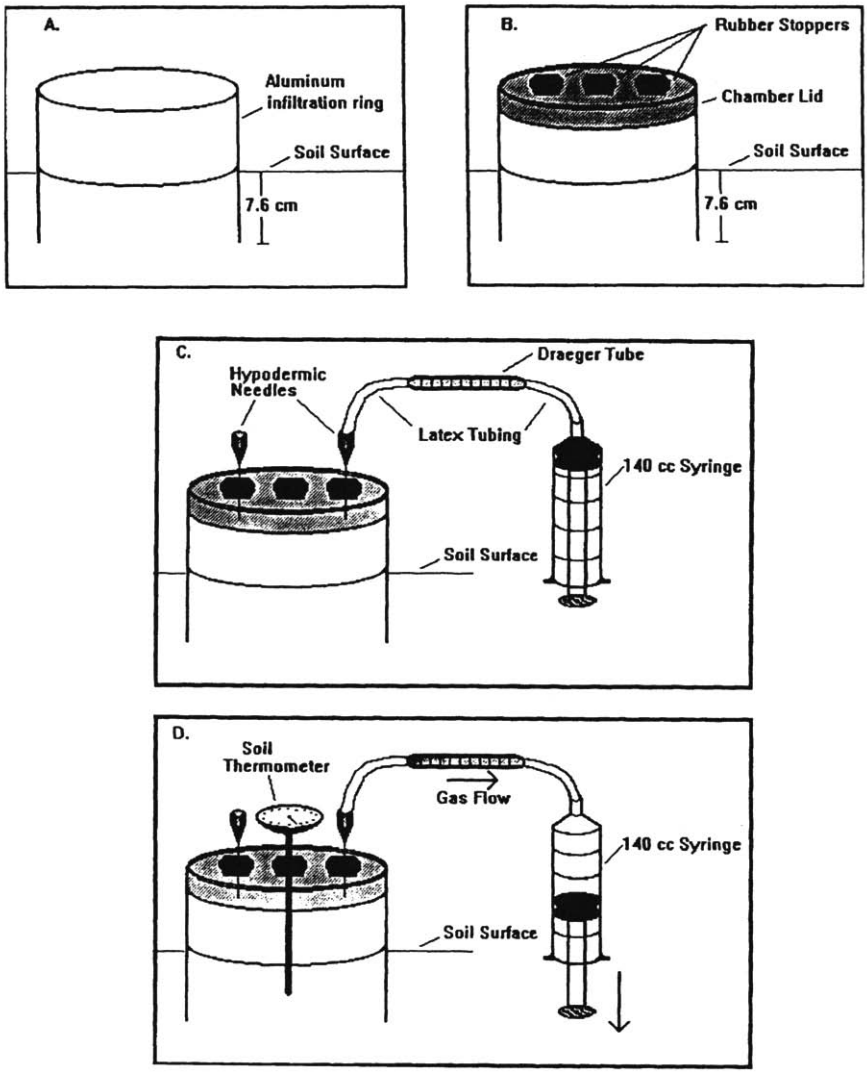

Fig. 14–1. Schematic diagram of soil respiration methodology.

6. Install soil thermometer through the central stopper in the lid of the chamber to a depth of 5 cm (2 in) in the soil (Fig. 14–1D). Record soil temperature and percentage of CO_2 at time of sampling.

Calculations

The CO_2 reading from the Draeger tube must be converted from units of volumetric percentage to grams of CO_2–C per square meter of soil. The critical factor that influences this calculation is the chamber headspace volume, which is a function of how high the chamber extends above the soil surface. According to

the procedure above, the chamber headspace height should be approximately 5 cm (2 in), however, if the soil surface is uneven the average soil can height above the surface must be determined by measuring the soil chamber height at several places within the ring. Once the average height of the chamber above the surface is determined (in centimeters) it is inserted into the following formula.

$$\text{g } CO_2\text{–C m}^{-2}\text{ d}^{-1} = (h/5.1) \times PF \times [(ST + 273)/273] \times [\%CO_2 - 0.035] \times 13.0 \quad [1]$$

where h is the average headspace height in cm, PF equals inches Hg barometric pressure/29.9, and ST is the soil temperature at 5 cm (°C). Note the barometric pressure factor, PF, can be ignored if the elevation is <2000 ft. The constant of 13.0 used in this equation assumes a chamber height of 5.1 cm and a measurement time of 0.5 h. Derivation of this constant is as follows:

$$(\%CO_2 - 0.035)/100 \times (12\text{ g C}/22\,400\text{ cm}^3) \times (889\text{ cm}^3\text{/chamber}) \times [(10^4\text{ cm}^2\text{/m}^2)/(174.8\text{ cm}^2\text{/chamber})] \times (48\text{ one-half h d}^{-1}) = (\%CO_2 - 0.035) \times 13 = \text{g } CO_2\text{–C m}^{-2}\text{ d}^{-1}.$$

Respiration in units of kg CO_2–C ha d^{-1} can be obtained by multiplying g CO_2–C m^{-2} d^{-1} by 10.

Methodological Variations

In many situations it may be desirable to compare CO_2 flux values from different sites or at the same site at different times, however, differences in soil temperature and soil water content, may introduce variability into such comparisons. In order to facilitate site or time comparisons it is desirable to normalize CO_2 flux values to some defined standard conditions of soil temperature and water content. Soil temperature corrections can be performed using the general rule that biological activity increases by a factor of 2 with each 10°C increase in temperature. If normalization of CO_2 flux rates is desired we suggest use of a standard temperature of 25°C. The following formula indicates how this temperature correction is made.

$$\text{Standardized } CO_2 \text{ Flux Rate} = R \times 2^{[(25 - T)/10]} \quad [2]$$

where R is the measured CO_2–C flux rate, and T is the measured temperature in °C at the time of sampling. This standardization formula is only recommended when the measured soil temperature is between 15 and 35°C. Between 0 and 15°C Eq. [3] is used.

$$\text{Standardized } CO_2 \text{ Flux Rate} = R \times 4^{[(25 - T)/10]} \quad [3]$$

Soil water content is another factor that influences CO_2 flux rate. Standardization of field soil respiration determinations is based on laboratory obser-

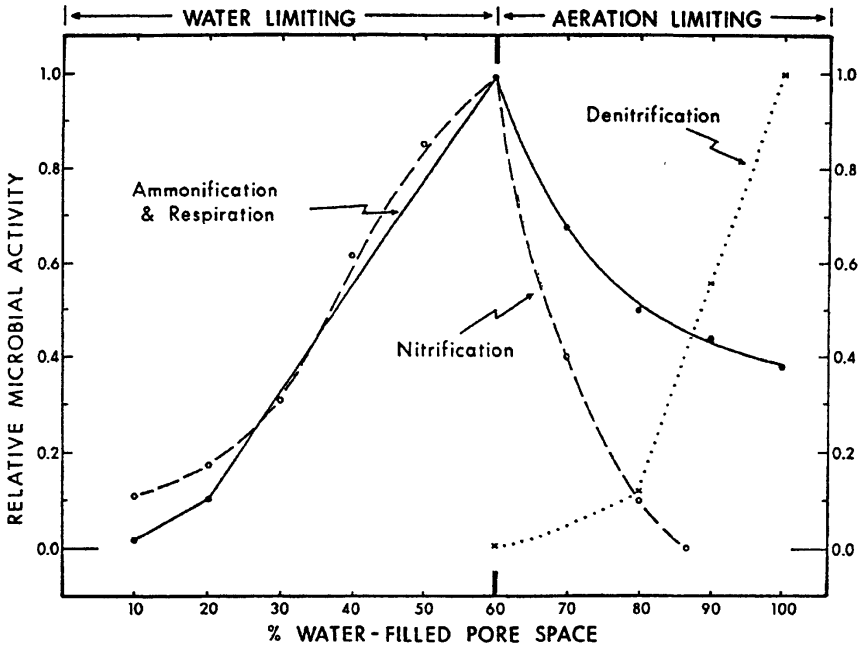

Fig. 14–2. Relationship between aerobic and anaerobic microbial processes and the percentage of water-filled pore space (after Linn & Doran, 1984).

vations for a wide range of soils that indicate maximum aerobic microbial respiration occurs when 60% of the soil pores are filled with water (Doran et al., 1990; Linn & Doran, 1984). As illustrated in Fig. 14–2, aerobic microbial activity increases linearly with water-filled pore space (WFPS) up to about 60% WFPS, and then decreases at higher water contents, apparently due to limited aeration. The base level of 0.4 relative activity for respiration (CO_2 production) and ammonification at saturated conditions is apparently due to a reduced rate of ammonification and CO_2 production under anaerobic conditions. Respiration rates can be adjusted to equivalent values at 60% WFPS through use of the following equations, where R_{60} is the adjusted respiration rate normalized to 60% WFPS.

For WFPS between 30 and 60%;

$$R_{60} = \text{measured respiration rate} \times (60/\text{measured \%WFPS}) \quad [4]$$

For WFPS between 60 and 80% WFPS;

$$R_{60} = \text{measured respiration rate}/[(80 - \text{\%WFPS}) \times 0.03] + 0.4 \quad [5]$$

These equations are empirical derivations from the respiration response observed in Fig. 14–2. Respiration rates measured in the field when soil water status exceeds 80% WFPS are not dependable since diffusion of CO_2 into the chamber may be restricted by wet conditions. We caution that although microbial respiration shows a strong relationship to %WFPS in the laboratory, the relationship

between %WFPS and soil respiration has not been extensively evaluated in the field.

Other methodological variations are possible, especially related to chamber size and CO_2 detection techniques. Larger chambers should, theoretically, reduce the spatial variability associated with field CO_2 flux measurements. Also, portable infrared gas analyzers enable real time CO_2 determinations that allow for short term (i.e., 2 min or less) flux determinations that should reduce biases associated with changes in soil conditions resulting from chamber placement.

Method 2: Microbial Respiration

In many cases field respiration measurements do not directly indicate microbial respiration, due to the presence of plant roots, and other soil organisms; however, microbial respiration can be measured if these other sources of CO_2 are removed through the sieving and mixing process. It is proposed that microbial respiration be assessed in laboratory incubations on sieved soil. Laboratory measurement should be conducted on sieved soil packed in a beaker at bulk density of 1.0 g cm^{-3}, (or to the natural reconsolidation density of the soil being tested), incubated at 60% WFPS, and at a temperature of 25°C. Microbial respiration is the cumulative CO_2–C produced during a 0- to 10- or a 0- to 20-d incubation period. Details on implementation of this method are presented in the description of the microbial biomass measurement (Rice et al., 1996, this publication).

INTERPRETING SOIL RESPIRATION MEASUREMENTS

The most difficult task in the development of a soil quality index is ascribing an interpretation to those soil attributes identified as important or valuable soil quality indicators. Interpretation of soil indicator measurements relative to soil quality is entirely dependent upon the precise definition or perception of soil quality. In the development of a definition of soil quality, a critical question that must be answered is "Why does the soil have value?". Only after the value of soil has been defined, can soil attributes that contribute to this ascribed value be identified.

Two general approaches have been proposed for interpretation of soil quality indicators. One of these approaches promotes the use of the soil characteristics of natural or undisturbed soils as the benchmark by which soil quality can be judged. With this approach it is assumed that the natural or undisturbed system is *best*. A second approach has been to interpret soil quality indicators in relation to soil function. Doran and Parkin (1994) proposed a general framework for assessment of soil function based on measured soil attributes. In this chapter, we adopt the second approach, and attempt an interpretation of soil respiration based on soil function.

In general terms, soil respiration represents the activity of the soil biotic component (Fig. 14–3), including microbial activity (bacteria, actinomycetes, fungi, algae, and protozoa), invertebrate activity (e.g., nematodes, gastropods, earthworms, and insects), and plant root activity. This biological activity is a

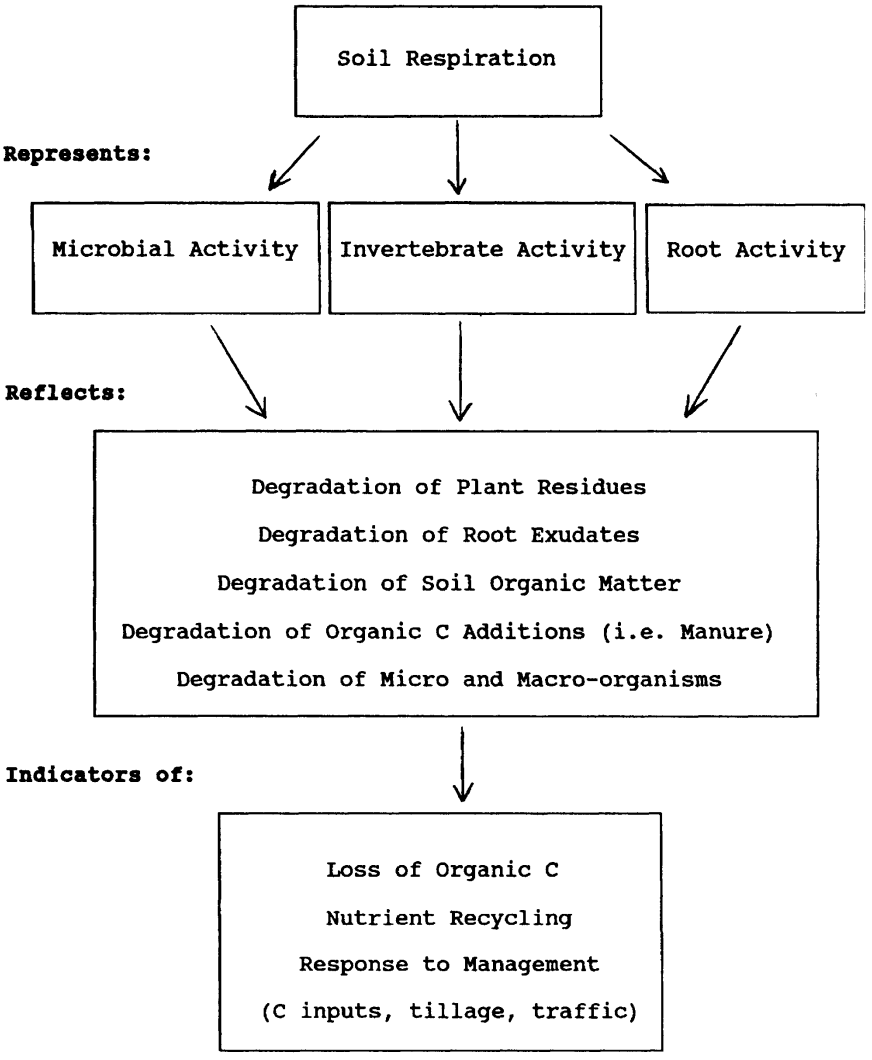

Fig. 14–3. Diagrammatic interpretation of respiration as a soil quality indicator.

direct reflection of the degradation of organic C compounds in soil. These organic C compounds may reside in a variety of different forms or pools including plant residues and root excretions, soil organic matter, organic C amendments such as manure, and the residues of dead micro- and macro-organisms. Interpretation of soil respiration measurements relative to soil quality must identify how soil respiration relates to soil function. Figure 14–3 indicates that organic C decomposition reflected by soil respiration is indicative of two important processes in soil: (i) loss of soil C and (ii) the turnover (release and stabilization) of nutrients. In addition, soil respiration may represent a sensitive indicator of the response of the soil biotic component to management such as plant residue or animal manure addition, tillage, and traffic.

Table 14–2. Beneficial effects of microorganism on soil.

Recycle nutrients (release nutrients to plants)
Promote soil structure
Degrade toxic compounds
Build stable soil organic matter
Degrade crop residues
Degrade animal material
Control the activities–populations of harmful microorganisms (through competition–inhibition–predation)
Fix atmospheric N
Consume greenhouse gasses
Provide a pool of diverse genetic material
Provide a pool of readily available nutrients
Promote plant nutrient and water uptake

Microorganisms are key components of soil, and it has been proposed that soil respiration may be a potentially valuable indicator of microbial activity in soil. Because microorganisms perform many beneficial functions in soil (Table 14–2), it is generally regarded that high microbial activity is a positive indicator of soil quality; however, this perspective may be too simplistic. In addition to the positive functions of microorganisms in soil, microorganisms have detrimental impacts (Table 14–3). The situation is complicated by the fact that assessment of whether or not a given activity is positive or negative, depends upon when and where in the soil profile the activity occurs. For example, high pesticide degradation activity in soil may represent a positive function of soil in terms of serving as an environmental buffer; however, if high pesticide degradation activity is expressed too soon after the pesticide is applied, loss of pesticide efficacy may result. Indeed, soils in which this phenomenon has been observed to occur have often been referred to as problem soils. Thus, for one to accept the notion that the higher the soil respiration, the higher the soil quality, one must assume that soil respiration measurements only indicate the positive attributes microorganisms impart to soil and not the negative ones.

A method or framework for interpreting soil respiration measurements relative to specific functions carried out by soil microorganisms is needed. Unfortunately, due to the physical and chemical complexity of the soil environment, the diversity of soil microbial populations and other soil fauna, the variety of microbial processes that occur in soil, and the complex nature of soil organic C, development of a universal framework that relates a general measure of soil biotic

Table 14–3. Detrimental effects of microorganisms on soil.

Release nutrients at the wrong time
Degrade soil organic matter
Degrade crop residues
Degrade pesticides (loss of efficacy)
Plant pathogens
Human–animal pathogens
Produce greenhouse gasses
Control the activities–populations of beneficial microorganisms (through competition–inhibition–predation)

activity, such as soil respiration, to all the functions carried out by soil microorganisms appears doubtful.

Whereas identification of specific microbial function based on soil respiration may be an unrealistic expectation, soil respiration measurements do provide a direct assessment of a process of critical importance to soil function: loss of organic C. Organic C has a positive impact on soil in many ways. Organic C has been shown to be positively related with soil structure, water penetration, water retention, root development, and nutrient storage (Brady, 1984). Since a positive relationship between soil organic matter and a variety of soil functions (enhanced productivity, enhanced structure, and enhanced water entry and retention) can be conceptualized, and since soil respiration represents a loss of organic C, the overall relationship between soil respiration and soil quality may be a negative one.

A strict negative relationship between soil respiration and soil quality is too simplistic. In terms of crop production, the positive relationship between crop productivity and soil organic matter is due in part to the fact that plant nutrients are released as a result of organic matter degradation. Also, in terms of the structural benefits of organic matter (OM) only certain types of OM are beneficial (Roberson et al., 1995; Arshad & Schnitzer, 1987). This implies that microbial processing of organic residues in soil must occur before beneficial effects on structure are attained. Thus, soil respiration may indicate two opposing aspects of the relationship between soil organic matter and soil quality. In the long term, loss of soil organic matter can be viewed as a negative result of soil respiration, however, in the short term, respiration represents the release of plant available nutrients. From this perspective assignment of either a *more is better* relationship or a *more is worse* relationship between soil respiration and the plant productivity component of soil quality is not appropriate. Clearly, some optimum soil respiration must be defined that balances the long-term detrimental aspects of soil C loss through respiration, and the soil nutrient turnover that respiration represents.

To develop a soil quality interpretation of soil respiration relative to loss of organic C, and release of nutrients, each of these soil quality components must be assessed. Ideally, it would be advantageous to use a single measurement for assessment of both of these processes, however, currently there is no quantitative relationship between field CO_2 fluxes and nutrient release, and conversely laboratory measurements of CO_2 production may not adequately represent total C loss. Thus, at this stage it is advised that these two components, soil C loss, and soil nutrient release, be determined separately, by different methodology. Specifically, we propose: (i) the use of soil respiration measurements as determined by CO_2 flux in the field as an indicator of the soil organic matter storage potential of the soil, and (ii) the use of laboratory measurements of microbial respiration as an indicator of nutrient release, specifically, the N supplying potential of soil.

Respiration as a Predictor of Soil Organic Matter Storage

As previously mentioned, from a C storage perspective, soil respiration can be viewed as a negative attribute. Simply looking at absolute respiration rates may not be adequate to characterize a given soil system. High respiration rates exhibited by soils receiving high organic C inputs may provide a biased picture

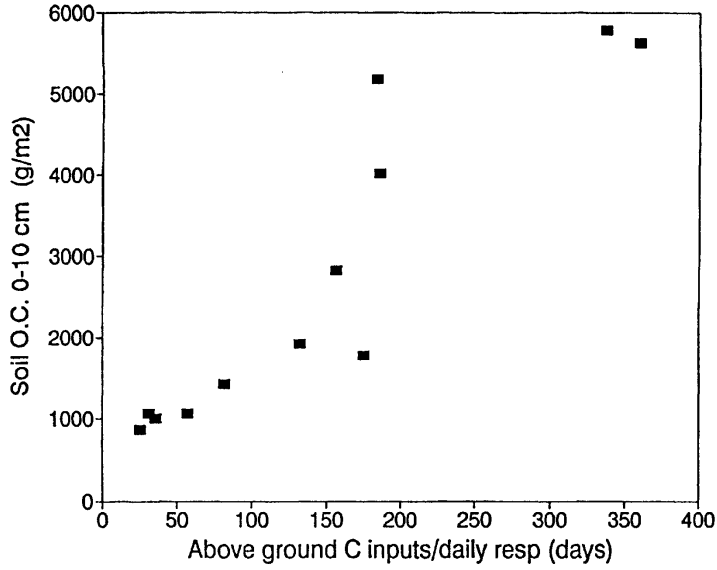

Fig. 14–4. Relationship between the ratio of aboveground plant inputs/soil respiration and soil organic matter (Parkin & Colvin, 1994, unpublished data).

of organic C storage. For example, in systems receiving high C inputs such as animal manures or green manure cover crops, the magnitude of the respiration response observed may be dominated by organic C amendments to soil. High respiration responses in such systems may indicate release of plant required nutrients but it indicates little in terms of whether or not the manure is being accumulated as soil organic matter. What is needed is some way to normalize or adjust soil respiration rates to account for differences in C inputs to the system.

In the assessment of a given soil's role in C storage it is not total C loss that is important, rather it is C loss relative to C inputs. From this C balance perspective if losses of organic C exceed C inputs, soil organic matter is being depleted. Thus, representation of soil respiration C losses in relation to C inputs may provide an indicator of the rate and direction of change of the soil organic matter pool. In practice it is difficult to quantify C inputs from plant production, primarily because assessment of below ground production is a tedious operation. An approximation may be obtained from above ground C inputs. As a rough estimate, the mass of C in the roots can be assumed to be approximately 62% of the aboveground plant residue C for wheat and 58% of the aboveground plant residue C for soybeans and corn (Buyanovsky & Wagner, 1986). Ideally, the amount of aboveground plant residue C should be measured directly, however, if C analyses are not available it can be assumed that the plant residue C is approximately 37% for wheat (*Triticum aestivum* L.), and 41% for corn (*Zea mays* L.), and soybeans [*Glycine max* (L.) Merr.; Buyanovsky & Wagner, 1986].

In a recent assessment of soil respiration in an agricultural field, a strong relationship was observed between the ratio of above ground C inputs to respiration and soil organic C content (Fig. 14–4).This relationship implies that the

longer it takes for the aboveground C inputs to decompose, the greater the chances that more organic C will be retained and hence the greater the probability of increased soil organic C. A similar relationship between soil respiration, crop production, and soil organic matter can be observed in data from studies conducted in Minnesota (Reicosky & Lindstrom, 1993; Reicosky et al., 1995). These investigators observed a burst of CO_2 from soils immediately following tillage, and a positive relationship was observed between the crop residue/CO_2 flux ratio and decreasing tillage intensity suggesting the soil organic C content of the plots with less tillage should increase soil organic matter.

Currently, precise values for a soil quality rating based on soil respiration cannot be set without additional data, however, we recommend that for comparative ranking purposes, the number of days to degrade the aboveground inputs may be a useful comparative tool. This information, if coupled with climate data (temperature and rainfall) may provide an indicator of changing organic C content of soils. This concept has been recently advanced in a soil quality rating system developed by the Natural Resources Conservation Service (NRCS, formerly the SCS) where regional residue inputs required to maintain soil organic matter at current levels are estimated (Argabright et al., 1991).

Microbial Respiration Relation to Nutrient Turnover

Microorganisms play a key function in nature through the release of nutrients from decomposition of dead plant and animal material. Control of the release of nutrients, and especially N is an important aspect of soil quality, from plant productivity and water quality perspectives. There have been several laboratory studies that show strong correlations between microbial respiration and net N mineralization. In 4-wk incubations of soil amended with a variety of animal manures, nearly a 1:1 response between CO_2 production and the amount of N released was observed by Castellans and Pratt, (1981). Similarly, Gilmour et al. (1985) found linear relationships between CO_2 production and N released in soil amended with organic materials. Slopes of the regression equations were nearly 1 for N-rich materials such as sewage sludge, alfalfa (*Medicago sativa* L.) and clover (*Trifolium* sp.), but for bermudagrass [*Cynodon dactylon* (L.) Pers] and rye (*Secale cereale* L.) amendments regression slopes were 0.43 and 0.53, respectively. These data were used to develop a model employing the C and N content of the organic substrate, and the respiration rate to predict N mineralization from added substrate. A strong relationship between CO_2 production and N-mineralization also exists for nonamended soils. Data from Smith et al.(1986) was used to compute ratios of cumulative CO_2–C produced net N mineralized during a 34-d incubation of 20.6 and 17.3 for a Palouse silt loam and a Walla Walla silt loam, respectively. Similar values have been observed for soils of central and south western Iowa (Table 14–4).

In terms of a soil quality index, there is little advantage gained in using laboratory derived microbial respiration data to predict N mineralization, when in fact net N mineralization can be measured directly in such incubations. The real value of these studies is the indication that a possible relationship between soil respiration and N mineralization in the field may be possible.

Table 14–4. Ratios of cumulative CO_2–C respired to net N mineralized For several Iowa soils (0 to 15 cm). Values were obtained from 30-d laboratory incubations of sieved soil packed to a bulk density of 1.0, at 60% water-filled pore space (WFPS), and an incubation temperature of 22°C.

Soil	Management	Cumulative CO_2/N-mineralized
Clarion loam	Restored Prairie	15.5
Clarion loam	Cultivate corn/soybean	17.3
Clearfield slc	CRP converted to cultivated corn/soybean†	16.9
Clearfield scl	CRP	13.8
Canisteo scl	Cultivated corn/soybean	16.5

† CRP, Conservation Reserve Program.

SUMMARY

In the process of developing of soil quality indicators it is critical to set targets or establish criteria that allow for interpretation of indicator measurements. Because respiration is an indicator of organic matter decomposition in soil, it reflects two general processes: (i) loss of C from the soil system, and (ii) recycling of nutrients. Either of these processes can be viewed as detrimental or beneficial depending upon the intended use of the soil, the magnitude of the respiration activity, and the temporal and spatial distributions exhibited by these processes. In this chapter we briefly outlined two proposed interpretations for field and laboratory respiration measurements. Exact targets or values that allow precise interpretation of soil respiration need to be established. This may have to be done on a site by site basis, to specifically account for the intended use of the soil, soil management, and climatic factors.

REFERENCES

Anderson, J.M., and J.S.I. Ingram. 1993. Tropical soil biology and fertility: A handbook of methods. p. 41–43. *In* Soil CO_2 evolution. CAB Int., Wallingford, Oxon, England.

Anderson, J.P.E. 1982. Soil respiration. p. 831–871. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Anthony, W.H., G.L. Hutchinson, and G.P. Livingston. 1995. Chamber measurement of soil-atmosphere gas exchange: Linear vs. diffusion-based flux models. Soil Sci. Soc. Am. J. 59:1308–1310.

Argabright, S., D. Breitbach, D. Shoup, D. Lightle, L. Oyer, C.L. Girdner, and L. Samson. 1991. Soil quality ratings for cropland management systems in the Midwest states. Midwest Soil Condition Rating Committee Tech. Rep. USDA-NRCS, Lincoln, NE.

Arshad, M.A., and M. Schnitzer. 1987. Characteristics of the organic matter in a slightly and in a severely crusted soil. Z. Pflanzenernahr. Bodenk. 50:412–416.

Brady, N.C. 1984. The nature and properties of soils. 9th ed. Macmillan Publ. Co., New York.

Buyanovsky, G.A., and G.H. Wagner. 1986. Post-harvest residue input to cropland. Plant Soil 93:57–65.

Castellans, J.Z., and P.F. Pratt. 1981. Nitrogen mineralization of manure nitrogen-correlation with laboratory indexes. Soil Sci. Soc. Am. J. 45:354–357.

Doran, J.W, L.N. Mielke, and J.F. Power. 1990. Microbial activity as regulated by soil water-filled pore space. p. 94–100. *In* Trans. of the 14th Int. Congress of Soil Sci., Kyoto, Japan. 12–18 Aug. 1990. ISSS, Wagenigen, the Netherlands.

Doran, J.W, and T.B. Parkin. 1994. Defining and assessing soil quality. p. 1–22. *In* J.W. Doran et al. (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA, Madison, WI.

Gilmour, J.T., M.D. Clark, and G.C. Sigua. 1985. Estimating net nitrogen mineralization from carbon dioxide evolution. Soil Sci. Soc. Am. J. 49:1398–1402.

Howard, A. 1947. The soil and health. Devin-Adair, New York.

Kennedy, A.C., and R.I. Papendick. 1995. Microbial characteristics of soil quality. J. Soil Water Conserv. 50:243–248.

Linn, D.M., and J.W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled soils. Soil Sci. Soc. Am. J. 48:1267–1272.

Nay, S.M, K.G. Mattson, and B.T. Bormann. 1994. Biases of chamber methods for measuring soil CO_2 efflux demonstrated with a laboratory apparatus. Ecology 78:2460–2463.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv. 50:253–261.

Reicosky, D.C., and M.J. Lindstrom. 1993. Fall tillage method: Effect on short-term carbon dioxide flux from soil. Agron. J. 85:1237–1243.

Rice, C.W., T. Moorman, and M. Beare. 1996. Role of microbial biomass carbon and nitrogen in soil quality. p. 203–215. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality. SSSA Spec. Publ. 49. SSSA, Madison, WI.

Roberson, E.B., S. Sarig, C. Shennan, and M.K. Firestone. 1995. Nutritional management of microbial polysaccharide production and aggregation in an agricultural soil. Soil Sci. Soc. Am. J. 59:1587–1594.

Sarrantonio, M., J.W. Doran, M.A. Liebig, and J.J. Halvorson. 1996. On-farm assessment of soil quality and health. p. 83–105. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality. SSSA Spec. Publ. 49. SSSA, Madison, WI.

Smith, J.L., B.L. McNeal, H.H. Cheng, and G.S. Campbell. 1986. Calculation of microbial maintenance rates and net nitrogen mineralization in soil at steady-state. Soil Sci. Soc. Am. J. 50:332–338.

Turco, R.F., A.C. Kennedy, and M.D. Jawson. 1994. Microbial indicators of soil quality. p. 73–90. *In* J.W. Doran et al. (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA, Madison, WI.

Waksman, S.A. 1927. Microbiological analysis of soil as an aid to soil characterization and classification. J. Am. Soc. Agron. 19:297–311.

Zibilske, L.M. 1994. Carbon mineralization. p. 835–864. *In* R.W. Weaver et al. (ed.) Methods of soil analysis. Part 2. SSSA Book Ser. 5. SSSA, Madison, WI.